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THE EFFECT OF HELMET FORM ON HEARING: SPEECH INTELLIGIBILITY AND SOUND LOCALIZATION

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September 1972

HUMAN ENGINEERING LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

This report presents the results of an investigation of the effects of a standard and of an experimental helmet on speech intelligibility and sound localization.

Eight enlisted men with no hearing deficits were used as subjects.

Intelligibility was tested with the American Standard Method for Measurement of Monosyllabic Word Intelligibility. Localization error was determined for three groups of noise bands one octave wide with center frequencies of 250, 2000 and 8000 Hz.

There were no practical differences between the two helmets, nor between the bareheaded and helmeted conditions with either helmet.

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THE EFFECT OF HELMET FORM ON HEARING:

SPEECH INTELLIGIBILITY AND SOUND LOCALIZATION

INTRODUCTION

The experiment described in this report is one of a number of current and projected investigations aimed at developing comprehensive criteria for the evaluation of life-support systems. As a participant in the U. S. Army Materiel Command Five-Year Personnel Armor System Technical Plan (10), the Human Engineering Laboratory's primary responsibility is to provide a battery of standardized tests applicable to existing and prototype armor ensembles. The overall experimental approach shown in Figure 1 indicates that the standardized tests will ultimately be based on both laboratory experiments and field studies, on objective and subjective measures, and on individual and group performances.

This report presents the results of the second and third phases of a three-phase effort to quantify the effects of helmet form on hearing. During the first phase (reported separately), the effects of the standard M-1 helmet and an experimental helmet (Hayes-Stewart, Fig. 2) on free-field thresholds were determined (7). Phase Two is an evaluation of the helmets' effects on speech intelligibility, and Phase Three is an investigation of the effects of the helmets on sound localization.

PHASE 2: SPEECH INTELLIGIBILITY

METHOD

It was noted during Phase One that the M-1 helmet slightly raised the free-field thresholds of the wearers. The Hayes-Stewart helmet had the same effect, but to a lesser degree. The threshold elevation was frequency-dependent and was most evident at 4000 and 8000 Hz. These frequencies are at the upper end of what is normally considered to be the bandwidth of human speech (300 to 6000 Hz), and they contribute materially to speech intelligibility (6). Speech intelligibility is defined as the ability not only to hear, but also to understand transmitted speech (5). This ability is reflected in an intelligibility score: the percentage of correctly-received words. This experiment evaluated the effects of three different Speech Interference Levels (SILs) on speech intelligibility under three different head conditions: barehead, standard M-1 helmet and the experimental Hayes-Stewart helmet. A speech interference level is the arithmetic mean of the Sound Pressure Levels (SPLs) in dB (re: 0.0002μ bar) of the three octave bands centered on 500, 1000 and 2000 Hz. The three background SILs were ambient, 17.5 dB; low noise, 61.0 dB; and high noise, 72.0 dB.

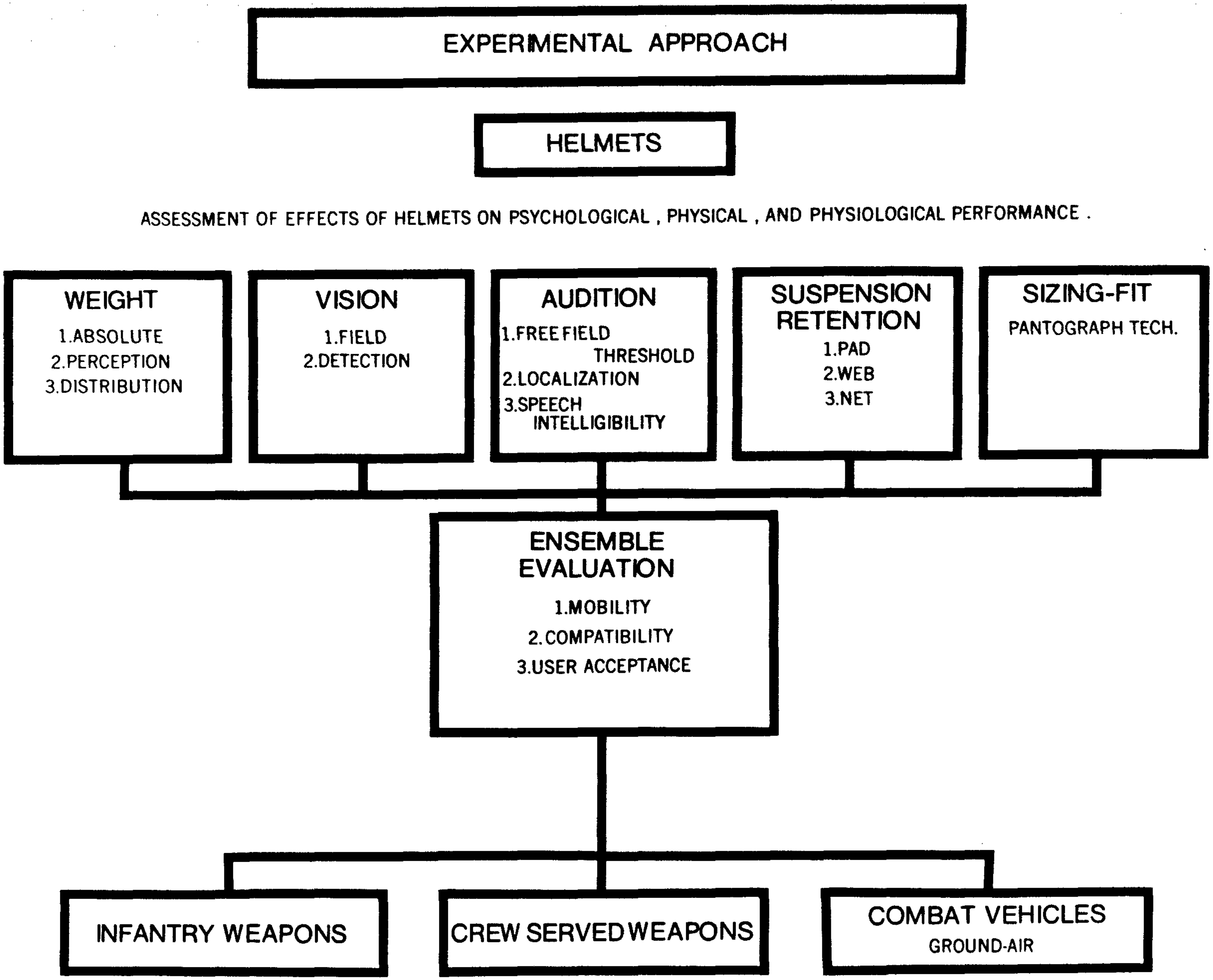

Fig. 1. HUMAN FACTORS EVALUATION OF INFANTRY HELMETS: EXPERIMENTAL APPROACH

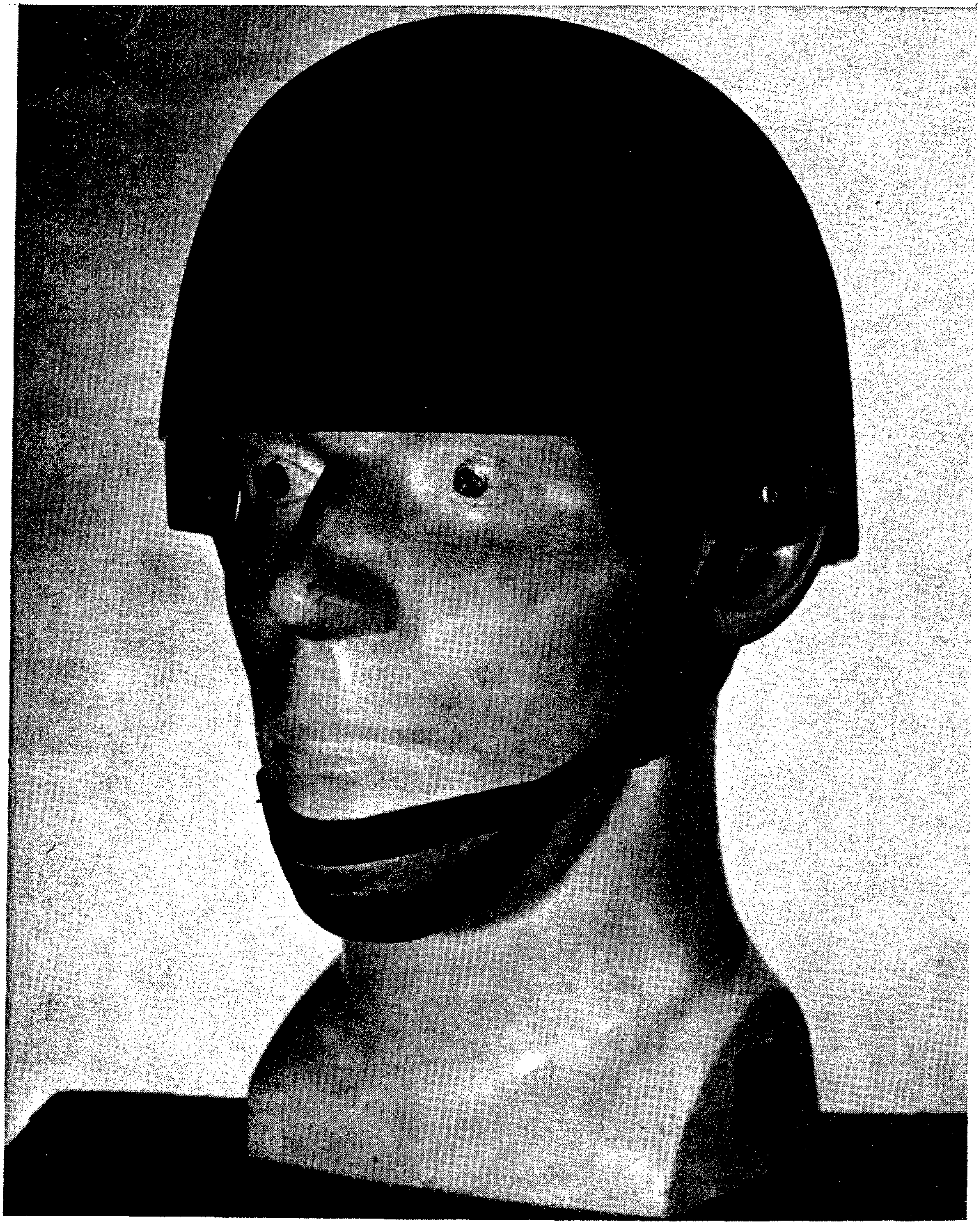

Fig. 2. HAYES-STEWART HELMET

It was assumed that the wearing of headgear would primarily affect the subject's (S's) ability to hear, and therefore there would be no need to train the Ss as talkers. A modified version of the American Standard Method for Measurement of Monosyllabic Speech Intelligibility (ASA S3.2-1960) was employed (1). The Ss listened to tape-recorded PB-50 word lists. These are "phonetically-balanced" lists of 50 monosyllabic words. The speech sounds occur in the same proportion as in everyday speech. The lists were recorded by a trained talker with no noticeable regional accent or speech defects. Each keyword was presented in a carrier sentence "Would you write (keyword) now." The words were presented at a uniform level of 80 dB at four-second intervals. Word lists one through 18 were used to give a test vocabulary of 900 words. Three different randomizations of the standard lists were used to avoid learning effects.

Subjects

Eight Ss participated in this experiment. They were all enlisted infantrymen who were assigned to HEL for temporary duty. The Ss were given a screening audiogram to insure that they had no greater than a 25-dB hearing loss at 250, 500, 1000, 2000 and 4000 Hz, with an average loss no greater than 20 dB overall.

Apparatus

The Ss were seated on lightweight folding chairs at a folding table in an Industrial Acoustics Company (IAC) reverberant chamber. The approximate volume of the chamber was 740 cubic feet.

The background noise field was generated by a Bruel and Kjaer (B&K) Type 1402 Random Noise Generator. The signal was fed first to a B&K Type 1612 S2 Spectrum Shaper, then amplified by a McIntosh MC-75 amplifier. The amplified signal was reproduced in the reverberant chamber by an Electrovoice "Patrician" loudspeaker. To insure that the desired SILs were being produced, the chamber noise field was sampled by a B&K Type 4144 microphone which was connected through a B&K Type 2604 microphone amplifier to a B&K Type 1612 Band-pass filter set, where the SILs were monitored (Fig. 3).

The PB-50 word lists were recorded and reproduced on a Nagra Model 3 tape recorder. During the tests, the recorder was centered on the table around which the Ss sat.

Procedure

For training, the Ss sat in a quiet room and recorded the keywords on answer sheets. When all of the Ss achieved intelligibility scores of at least 95 percent, training was ended. Testing in the reverberant chamber began on a schedule which randomized noise levels, head conditions and word lists. An observer was in the chamber with four Ss during each of the test periods.

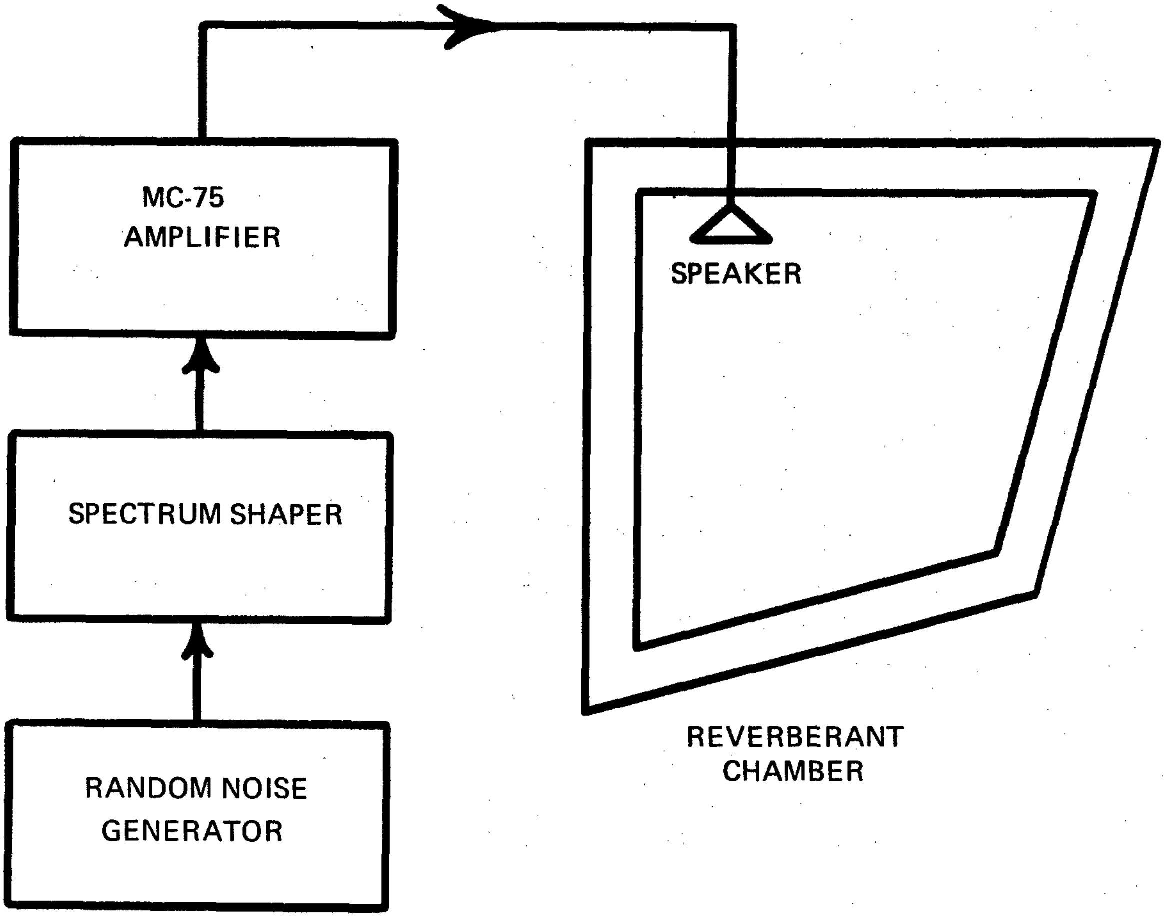

Fig. 3. BLOCK DIAGRAM OF SPEECH INTELLIGIBILITY APPARATUS

RESULTS AND DISCUSSION

The ASA intelligibility test is commonly used in the evaluation of intercommunication systems. Depending upon the circumstances of its use, if an intelligibility score of 70 percent is achieved over a given system, it is usually considered acceptable (4).

Figure 4 shows the mean intelligibility scores for each of the head conditions at each of the three noise levels.

Speech intelligibility was differentially affected by both the type of headgear and the SIL of the background noise. As expected, speech intelligibility was best under ambient conditions (SIL-17.5 dB). The lowest score (97.5%) under this condition was achieved by the Ss wearing the Hayes-Stewart helmet. The Ss would miss only 25 words out of 1000.

At the low-noise condition (SIL-61.0 dB), the Hayes-Stewart helmet scores were again lowest at 96.5 percent. Thirty-five words would be missed out of every 1000.

Under high-noise conditions (SIL-72.0 dB), the M-1 helmet scores were lowest at 89.7 percent. One hundred and three words would be incorrectly received out of 1000.

The largest mean difference between types of headgear was observed under the high-noise condition. A difference of only 1.3 percent (thirteen words per thousand) was found between the M-1 and Hayes-Stewart helmets.

PHASE 3: SOUND LOCALIZATION

METHOD

The third phase of the program was designed to determine what, if any, effects the standard M-1 and experimental Hayes-Stewart helmets have on the ability of the wearers to localize sounds.

Subjects

Eight Ss participated in this experiment. They were all enlisted infantrymen who were assigned to HEL for temporary duty. The Ss were given a screening audiogram to insure that they had no greater than a 20-dB hearing level, i.e., no greater than a 10 dB loss at 250, 500, 1000, 2000 and 8000 Hz.

Apparatus

Each S was seated on a special chair in an Industrial Acoustics anechoic chamber. At ear level (45" above the floor) around the S's left side was an array of 22 loudspeakers subtending an arc of 176 degrees at a radius of 125 cm from the S's head. The speakers were five-inch diameter Jensen "Concert Series" units, spaced approximately eight degrees apart.

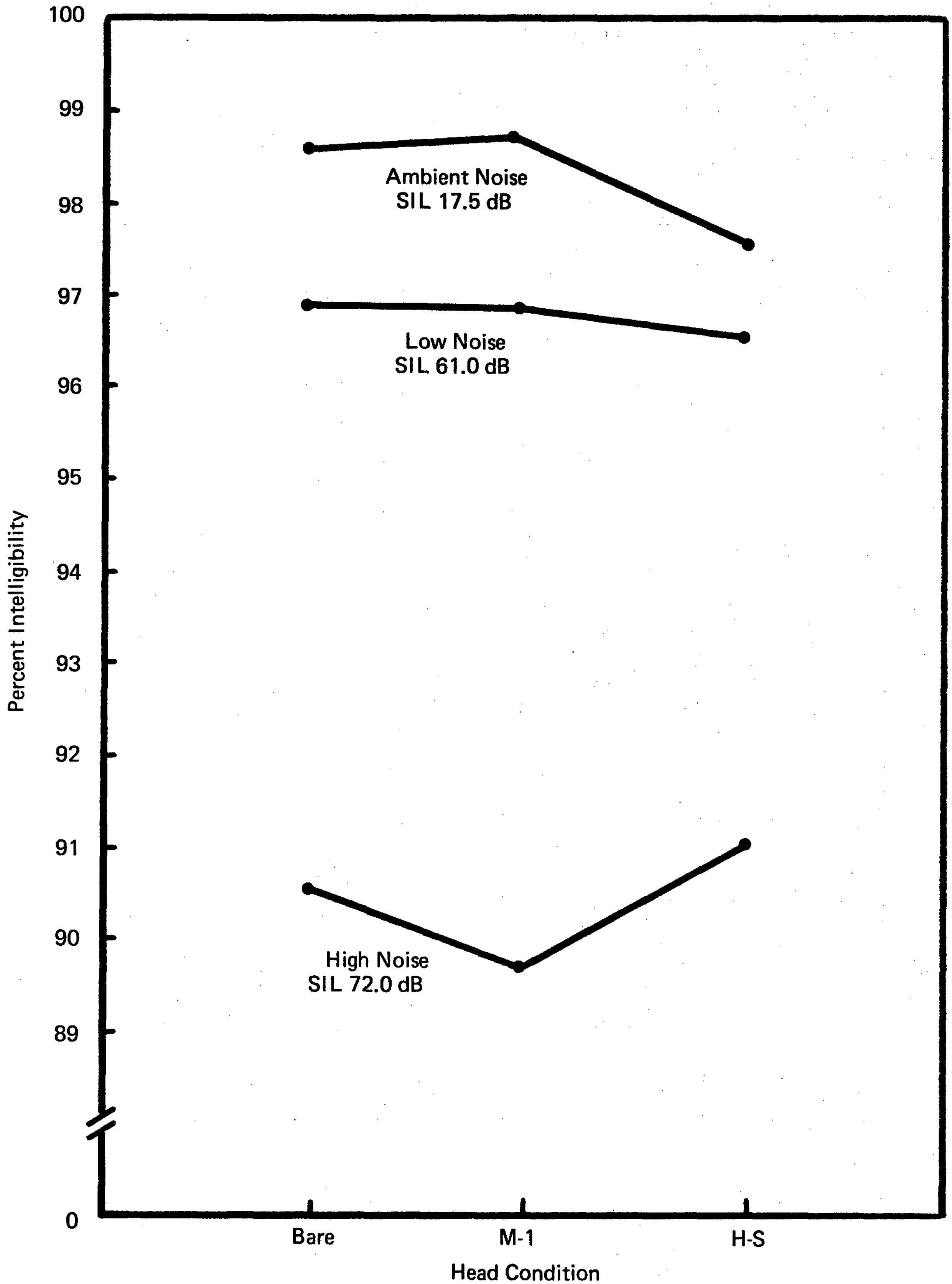

Fig. 4. EFFECT OF HEAD CONDITION ON SPEECH INTELLIGIBILITY

The stimulus signals were produced by a Bruel and Kjaer (B&K) Type 1402 Random Noise Generator, and fed to a B&K Type 1612 Bandpass filter set for spectrum shaping. The signals next passed through a Grason-Stadler Model 829E Electronic Switch for timing, then through a matching transformer (600 to 3.2 ohms) to a 22-position speaker selector switch. The signals could then be routed to any desired speaker (Fig. 5).

Facing the S was a small panel on which was mounted a half-circle, marked off in degrees, corresponding to the speaker array and showing zero degrees behind the S, 90 degrees adjacent to the left ear, and 180 degrees to the S's front. The major graduations were labelled in 10-degree increments.

A talk-back system consisting of a B&K Type 4132 microphone with a B&K 2613 cathode follower and a B&K Type 2604 Microphone Amplifier feeding a monitor speaker was used by the S for verbally reporting the perceived direction of sound during each trial. The microphone and cathode follower were the only components of the talk-back system inside the chamber and were always "hot."

Procedure

One at a time, the Ss were seated in the anechoic chamber, wearing one of the two helmets or no helmet, according to the randomization schedule. The head condition was the same throughout each test period. A test period consisted of 22 tone presentations, one from each of the speakers in the array. The tones were broad-band noise one-octave wide with center frequencies of 250 Hz (low), 2000 Hz (medium), 8000 Hz (high). Each trial consisted of a 3.0-second tone presentation, after which the S verbally reported the perceived source direction in degrees via the talk-back microphone. The head condition, tone center frequency and speaker were randomized. The test periods were spread over a six-day period so that each S heard each tone through each speaker under each head condition at least eight times.

RESULTS AND DISCUSSION

The difference in degrees between the actual and reported position of the source was taken as a measure of localization error. Front-back reversals were not counted as errors, since there were no cues by which the Ss could distinguish in which quadrant the sounds originated (8). Thus, if a tone originated at 44½ degrees (speaker # 6), but was reported as coming from 136½ degrees (speaker #17), no error was counted.

Figure 6 shows localization errors as a function of speaker position for each of the three head conditions.

It can be seen that localization errors were lowest when the sound source was near the medial plane (both front and rear) and at approximately a right angle to it. Errors for sounds originating in the front quadrant were lower than for the corresponding points of origin in the rear quadrant.

Similarity of effect can be seen for all three head conditions. Table 1 shows the maximum mean localization error differences between head conditions.

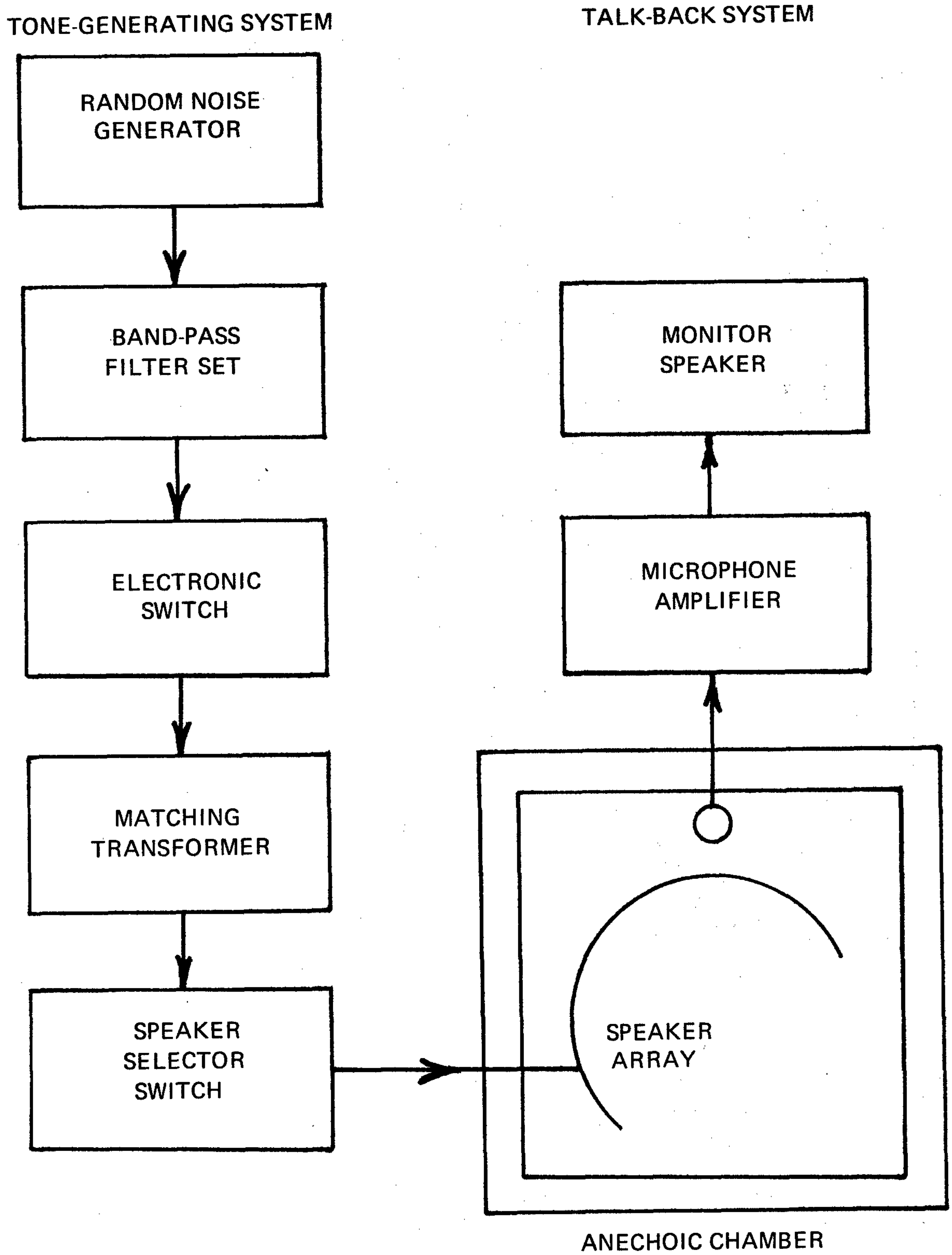

Fig. 5. BLOCK DIAGRAM OF SOUND LOCALIZATION APPARATUS

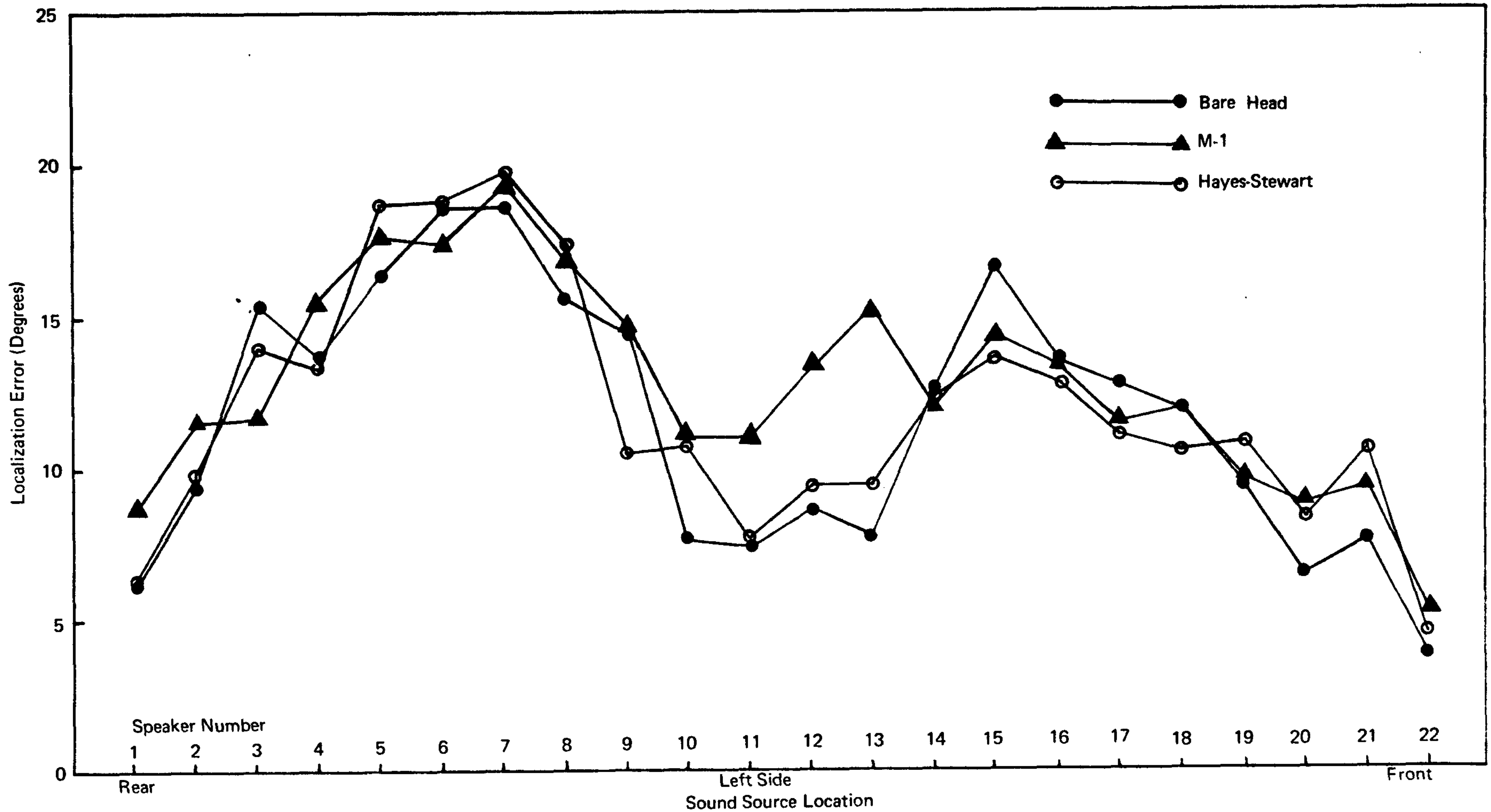

Fig. 6. EFFECT OF HEAD CONDITION ON SOUND LOCALIZATION

TABLE 1

Mean Head Condition Differences
(Degrees)

	Bare Head	M-1	Hayes-Stewart
Bare Head	-----	7.28	4.0
M-1	-----	----	5.5
Hayes-Stewart	-----	----	----

The largest mean difference was between the bare head and M-1 helmet conditions at approximately 70 degrees. The bare-head error at that position was only 7.5 degrees. The M-1 helmet error was twice as large; 15.0 degrees. The Hayes-Stewart error at that position was 9.5 degrees.

Figure 7 shows localization error as a function of speaker position for each of the three tone conditions.

It can be seen that there is very little difference in localization error among the three tones. High tones seemed to be comparatively poorly localized in the rear quadrant. Table 2 shows the mean localization error differences among tones.

TABLE 2

Mean Tone Differences
(Degrees)

	Low	Medium	High
Low	------	5.0	7.5
Medium	------	-----	7.0
High	------	-----	-----

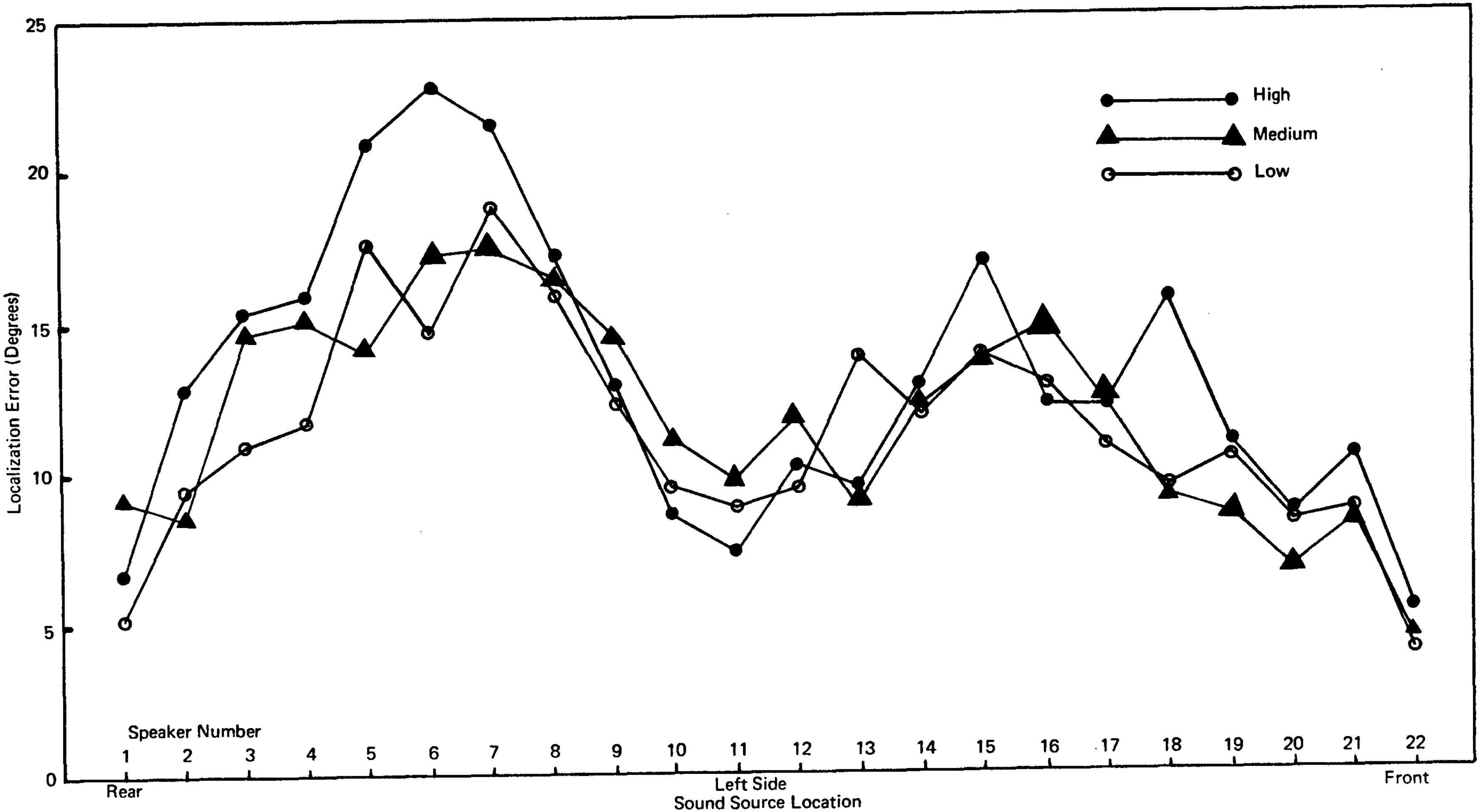

Fig. 7. EFFECT OF TONE FREQUENCY ON SOUND LOCALIZATION

The largest mean difference was found between low and high-center frequency tones--7.5 degrees. As in head-condition differences, this is an insignificant difference.

Figures 6 and 7 indicate that the sound sources are most accurately located when they are nearest the medial plane. Front-quadrant sounds are localized slightly more accurately than those originating in the rear quadrant. Stevens and Newman (9) attribute this difference to the "pinna effect" (sound shadows caused by the external ear). This effect did not seem to be intensified by the wearing of a helmet. They also report that high-frequency tones are localized by differences in intensity at the two ears. When the source is at the side, the source direction must change through rather large angles before an intensity change can be perceived. It was found that localization was very nearly as good at 90 degrees as at the front and rear positions. The high-frequency tone was most poorly localized when the source was at approximately 45 degrees. It is at this position where the expected pinna effect should be most noticeable. There was some pinna effect when localizing low and medium tones, but the amounts of error were smaller than for high frequencies.

It was expected that the low tones and high tones would be localized more accurately than the medium-frequency tones. With both low and high-frequency tones, there are clear-cut factors contributing to accuracy of localization.

Low frequencies are localized through differences in phase of the signal since it arrives at the two ears at different times. High frequencies are localized by interaural intensity differences. Phase differences are cancelled due to the signal wavelengths being small in relation to the dimensions of the head. In the mid-frequency range, neither phase nor intensity differences are clearly the mechanism by which sounds are localized, and the listener experiences confusion. Present findings, however, show that the mid-frequency tones were localized about as accurately as both high and low-frequency tones.

A localization experiment comparing the Hayes-Stewart with the M-1 helmet was recently performed in a jungle environment at the U. S. Army Tropic Test Center (TTC) in Panama in cooperation with HEL (3). That experiment also determined that there were no statistically significant differences between head conditions. The sounds to be localized included two pure tones: 125 and 2000 Hz. The 125 Hz tone was more accurately localized than the 2000 Hz tone, probably because the jungle foliage scattered the high-frequency acoustic energy.

SUMMARY AND CONCLUSIONS

The investigation of the effects of headgear on speech intelligibility and sound localization were two phases of a three-phase program in support of the AMC Five-Year Personnel Armor System Technical Plan. The aim of this program is to develop more effective, acceptable helmets and body armor.

Under the broad category of "headgear hearing effects," there were three types of performance that could easily be measured: attenuation of signals, speech intelligibility and sound localization. In each of these three areas, it was possible to compare bare-headed performance with performance under a helmeted condition. Data were collected on these performance measures with the standard M-1 helmet and a prototype helmet (Hayes-Stewart). Thus, baseline performance could be determined and compared to both a standard and a candidate replacement helmet (2).

The investigation of the effects on speech intelligibility of headgear showed that intelligibility was affected both by headgear and by background noise. The effects, however, were so slight as to be of no practical significance. The largest mean difference between head conditions occurred under the two helmeted conditions. Intelligibility scores differed by only 1.3 percent. Under the worst noise condition -- an SIL of 72.0 dB -- the lowest score was 89.7 percent. This is considered to reflect excellent intelligibility. Intelligibility, then, was not appreciably degraded by either of the two helmets, nor by an SIL of 72.0 dB when the Ss were bare-headed.

Localization error did not differ by any significant amount between head conditions. The largest mean difference across all Ss was only 7.28 degrees for all tones. The three tones were localized about equally well -- the largest mean difference was only 7.50 degrees.

There were no practical differences between the M-1 and Hayes-Stewart helmets. Nor were there any practical performance level reductions for Ss wearing helmets.

RECOMMENDATIONS

The methods used in these evaluations were adequate to detect even minor differences between head conditions.

1. The evaluation of other helmet forms should consist of determinations of free-field thresholds and sound localization errors. Such evaluations should be performed only if there is complete pinna coverage or ear canal occlusion.

2. Because of the extensive tedious training required for speed intelligibility testing, this procedure should be deleted from the evaluation unless the free-field threshold data indicate substantial signal attenuation in the speech frequency spectrum.

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This report presents the results of an investigation of the effects of a standard and of an experimental helmet on speech intelligibility and sound localization.

Eight enlisted men with no hearing deficits were used as subjects.

Intelligibility was tested with the American Standard Method for Measurement of Monosyllabic Word Intelligibility. Localization error was determined for three groups of noise bands one octave wide with center frequencies of 250, 2000 and 8000 Hz.

There were no practical differences between the two helmets, nor between the bareheaded and helmeted conditions with either helmet.

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